Attachment 8
The Western Interior Basin

The Western Interior Coal Region comprises three coal basins that include the Arkoma, the Cherokee, and the Forest City Basins, and encompasses areas of six states: Arkansas, Oklahoma, Kansas, Missouri, Nebraska, and Iowa (Figure A8-1). The Arkoma Basin covers about 13,500 square miles in the states of Arkansas and Oklahoma, with an estimated 1.58 to 3.55 trillion cubic feet of gas reserves, contained primarily in the Hartshorne coals (Quarterly Review, 1993). The Cherokee Basin is part of the Cherokee Platform Province, which covers approximately 26,500 square miles (Charpentier, 1995) in the states of Oklahoma, Kansas, and Missouri. The basin contains an estimated 1.38 million cubic feet of gas in-place per square mile basin-wide (Stoeckenger, 1990) in the targeted Mulky, Weir-Pittsburg, and Riverton coal seams of the Cherokee Group (Quarterly Review, 1993), which calculates to approximately 36.6 billion cubic feet of gas basin-wide. However, the Petroleum Technology Transfer Council (1999) indicates that there is nearly 10 trillion cubic feet of gas in eastern Kansas alone. The Forest City Basin covers about 47,000 square miles (Quarterly Review, 1993) in the states of Iowa, Kansas, Missouri, and Nebraska, and contains an estimated one trillion cubic feet of in-place gas (Nelson, 1999). For the entire region, coalbed methane production was 6.5 billion cubic feet in 2000 (GTI, 2002).

8.1 Basin Coals

The Arkoma Basin is the southernmost of the three basins comprising the Western Interior Coal Region, and is bounded structurally by the Ozark Dome to the north, the Central Oklahoma Platform and Seminole Uplift on the west, and the Ouachita Overthrust Belt to the south (Quarterly Review, 1993). Middle Pennsylvanian coalbeds occur within the Hartshorne and McAlester Formations (Figure A8-2), as well as the Savanna and Boggy Formations (Quarterly Review, 1993).

The Cherokee Basin is the central basin of the Western Interior Coal Region, and is bounded on the east and southeast by the Ozark Dome, to the west by the Nehama Uplift, and on the north by the Bourbon Arch (Quarterly Review, 1993). Principal coals occur in the Krebs and Cabaniss Formations of the middle Pennsylvanian Cherokee Group (Figure A8-3).

The Forest City Basin (Figure A8-4), the northernmost basin of the Western Interior Coal Region, is a shallow cratonic depression bounded by the Nemaha Ridge to the west, the Thurman-Redfield structural zone to the north, the Mississippi River Arch to the east, and the Bourbon Arch to the south (Bostic et al., 1993). Methane-bearing coals occur in the middle Pennsylvanian Cherokee and Marmaton Groups, with the Cherokee Group being of primary interest (Tedesco, 1992).

8.1.1 Arkoma Basin Coals

The Hartshorne coals of the Hartshorne Formation are the most targeted for coalbed methane production in the Arkoma Basin, and range in depth from 600 to 2,300 feet in two productive areas in southeastern Oklahoma (Quarterly Review, 1993). Iannacchione and Puglio (1979) estimated that 58% of the coalbed methane in the Hartshorne coals in southeastern Oklahoma occurs at 500- to 1,000-foot depths. These coals can reach depths of greater than 5,000 feet, and are three to nine feet thick (Quarterly Review, 1993). Depths to the top of the Hartshorne coal in southeastern Oklahoma range from 380 to 1,540 feet (Friedman, 1982). As of March 2000, there were 377 coalbed methane wells in eastern Oklahoma, ranging in depth from 589 to 3,726 feet (Oklahoma Geological Survey, 2001).

8.1.2 Cherokee Basin Coals

The coal seams primarily targeted by operators in Kansas are the Riverton Coal of the Krebs Formation, and the Weir-Pittsburg and Mulky coals of the Cabaniss Formation (Quarterly Review, 1993). The Riverton and Wier-Pittsburg seams are about three to five feet thick and range in depth from 800 to 1,200 feet (Quarterly Review, 1993). The Mulky Coal, which ranges up to two feet thick, occurs at depths of 600 to 1,000 feet (Quarterly Review, 1993).

8.1.3 Forest City Basin Coals

Individual coal seams within the Cherokee Group in the Forest City Basin range from a few inches to about four feet in thickness, with seams up to 5 or 6 feet in thickness (Brady, 2002; Smith, 2002). Cumulative maximum coal thickness within the Cherokee Group is about 25 to 30 feet (Brady, 2002; Smith, 2002). Depths to the top of the Cherokee Group coals range from surface exposures in the shallower portion of the basin in southeastern Iowa to about 1,220 feet in the deeper part of the basin in northeastern Kansas (Bostic et al., 1993). In Nebraska, depth to the Cherokee Group is about 1,396 feet in one location, and the base is reached at a depth of 2,096 feet (Condra and Reed, 1959). Maximum thickness of the Cherokee and Marmaton Groups is about 800 feet in the southeastern tip of Nebraska (Burchett, unpublished paper).

8.2 Basin Hydrology and USDW Identification

8.2.1 Arkoma Basin Hydrology and USDW Identification

In Arkansas, the Arkoma Basin falls within the Interior Highlands physiographic province (Figure A8-5). According to the National Water Summary (1984), there is no principal aquifer in this area, only smaller alluvial aquifers bounding the Arkansas River (Figure A8-5). In these smaller alluvial aquifers, water wells typically penetrate to depths of 100 to 150 feet, and common well yields are on the order of 1,000 to 2,000 gallons of water per minute (National Water Summary, 1984). In Oklahoma, the Arkoma Basin is contained within the Ouachita and Central Lowland physiographic province

(Figure A8-6). Much like Arkansas, there are no principal aquifers in this portion of the state, but there are smaller alluvium and terrace deposits along the Arkansas, North Canadian, and Canadian Rivers (National Water Summary, 1984) that serve as aquifers (Figure A8-6). Marcher (1969) also identifies these smaller deposits as the most favorable for groundwater supplies. Water well depths in the alluvium and terrace deposits of the Arkansas River in Oklahoma typically range from 50 to 100 feet (National Water Summary, 1984). Water well production rates in all three aquifers commonly range from 100 to 600 gallons of water per minute in alluvium, and 50 to 300 gallons of water per minute in terraces (National Water Summary, 1984).

Bill Prior, a geologist with the Arkansas Geological Commission, stated that within Arkansas, the Arkoma Basin was in the Arkansas River Physiographic Province, which lacks a true aquifer. Most of the rocks within this physiographic province are tight sandstones and shales, and most communities within the province use surface water supplies (Prior, AGC, personal communication 2001). Doug Hansen of the Arkansas Geological Commission said that there were a few scattered bedrock wells within the Arkoma Basin (Hansen, AGC, personal communication 2001). Total dissolved solids (TDS) levels in the McAlester Formation in Arkansas (which contains the Hartshorne coals; see Potts, 1987) range between 55 to 534 mg/L at depths ranging from 32.4 to 190 feet below land surface (Cordova, 1963). The base of fresh water in the area is about 500 to 2,000 feet below ground surface (Cordova, 1963). However, Cordova (1963) does not define "fresh water." This makes it difficult to determine if the depths reported by Cordova coincide with the base of a USDW.

Water quality test results from the targeted Hartshorne seam in Oklahoma have shown the water to be highly saline (Quarterly Review, 1993). Ken Luza, a geologist with the Oklahoma Geological Survey, stated that a hydrologic atlas prepared by the Oklahoma Geological Survey delineated a 5,000 mg/L TDS water quality contour line in a portion of the state, including the Arkoma Basin (Marcher, 1969; Marcher and Bingham, 1971). Maps such as these atlas maps show that, based on water quality and rock type, very little of the area falls within an area "most favorable for groundwater supplies" or "moderately favorable for groundwater supplies." Most of the area falls within an area designated as "least favorable for groundwater supplies" (Cardott, 2002). Pam Hudson, Manager of the Geologic Section of the Oklahoma Corporation Commission, stated that the Commission has a series of maps, one for each county in Oklahoma, showing the elevation of or the depth to the 10,000 mg/L TDS line (Hudson, OCC, personal communication 2001). The primary criterion for a USDW is water quality with less than 10,000 mg/L TDS. The Oklahoma Corporation Commission maps are used to assist drillers in complying with state regulations that require oil and gas wells to be cased through USDWs.

The following table contains information concerning the relative location of potential USDWs and methane-bearing coalbeds in the Arkoma Basin.

Table A8-1 Relative Locations of USDWs and Potential Methane-Bearing Coalbeds, Arkoma Basin

Arkoma Coal Basin, States and Coal Group	Arkansas		Oklahoma	
	Depth to top of Coal [1] (ft)	Depth to base of Fresh Water [2,3] (ft)	Depth to top of Coal [1] (ft)	Depth to base of USDW [4] (ft)
Hartshorne Coals	0 to < 4,500	500 to 2000	> ~1000	< ~900

[1] Andrews et al., 1998
[2] Note: The base of "fresh water" is not the base of the USDW (depth to the base of the USDW is unknown or not available). Fresh water is within the USDW and the base of fresh water is above the base of the USDW. Cordova (1963) does not define "fresh water."
[3] Cordova, 1963
[4] Oklahoma Corporation Commission Depth to Base of Treatable Water Map Series (2001)

Based on Table A8-1, it can be determined that in Arkansas, there is a possibility for the Hartshorne Coals to be located within a USDW, allowing the potential for impacts. The potential for impacts from fracturing coalbeds below the USDW is not known. Cordova (1963) does not specify the TDS level used to determine the depth of the base of fresh water in the Arkansas Valley region; he merely states that it is the depth to salt water, and he does not provide a definition of "salt water." The position of a coalbed methane well within the basin would ultimately determine if coals and USDW's coincide, as the Hartshorne Coals are typically shallower on basin margins (Andrews et al., 1998) and progressively increase in depth toward the basin's center (potentially too deep to be located within a USDW).

8.2.2 Cherokee Basin Hydrology and USDW Identification

The Cherokee basin underlies parts of the states of Kansas, Missouri, and Oklahoma. In Kansas, the Cherokee Basin is part of the Central Lowlands and Ozark Plateaus physiographic provinces (Figure A8-7). While the majority of this area does not contain a principal aquifer, the Ozark and Douglas aquifers (Figure A8-7) are contained within the basin (National Water Summary, 1984). The confined Ozark aquifer, composed of weathered and sandy dolomites, typically contains water wells that extend from 500 to 1,800 feet in depth, commonly yielding 30 to 150 gallons of water per minute (National Water Summary, 1984). The usually unconfined Douglas aquifer is channel sandstone of Pennsylvanian age (National Water Summary, 1984). Water wells are usually five to 400 feet deep in this aquifer and typically produce 10 to 40 gallons of water per minute (National Water Summary, 1984).

In Missouri, only a very small portion of the basin falls within the Osage Plains area of the Central Lowlands physiographic province (Figure A8-8). The principal aquifers in this portion of Missouri are the Ozark and Pennsylvanian-Mississippian age aquifers (National Water Summary, 1984) (Figure A8-8). Water well depths in the Ozark aquifer typically range from 200 to 1,700 feet, and those in the Pennsylvanian-Mississippian age aquifers typically range from 100 to 400 feet in depth (National Water Summary, 1984). Common well yields are 15 to 700 gallons of water per minute and one to 15 gallons of water per minute in the Ozark and Pennsylvanian-Mississippian aquifers, respectively

(National Water Summary, 1984). Only a very small portion of the Cherokee Basin, bounded from the Forest City Basin to its north by the Bourbon Arch, falls within the state of Missouri (Figure A8-9). Jim Vandike, Chief of Missouri's Water Resources Branch at the state's Geological Survey, stated that only two public water supplies in Branch at the state's Geological Survey, mentioned that only two public water supplies obtained water from Pennsylvanian strata, and those wells were outside of the Cherokee Basin (Vandike, MGS, personal communication 2001).

In Oklahoma, the Cherokee Basin lies within the Central Lowland physiographic province (Figure A8-6). In addition to the alluvium and terrace deposit aquifers already discussed above in the Arkoma Basin aquifer descriptions, this area also contains the Garber-Wellington and Vamoosa-Ada aquifers (Figure A8-6), which are unconfined to confined sandstone with shale and siltstone aquifers (National Water Summary, 1984). Additionally, the Vamoosa-Ada aquifer contains some conglomerate aquifers as well. Water well depths in these two aquifers usually range from 100 to 900 feet in depth, and wells typically produce from 100 to 300 gallons of water per minute (National Water Summary, 1984). At least half of the area of this basin in Oklahoma does not contain a principal aquifer (National Water Summary, 1984).

In Kansas, Al Macfarlane, of the Kansas Geological Survey, stated that the Ozark Aquifer was located in the Cherokee Basin in Kansas (Macfarlane, KGS, personal communication 2001). An Ozark Aquifer Extent map indicates that the "usable" part of the aquifer (defined as less than 10,000 mg/L of TDS per Al Macfarlane; no definition of "usable" is provided by the map) covers the three southeastern-most counties (Bourbon, Crawford, and Cherokee) of the state (Figure A8-7) and parts of the adjacent four counties (Linn, Allen, Neosho, and Labette) (DASC Ozark Aquifer Extent Map, 2001). Since the elevation in that portion of the state is roughly 850 feet above sea level (DASC Kansas Elevation Map, 2001) and the elevation of the base of the Ozark Aquifer is roughly 900 feet below sea level (Ozark Aquifer Base Map, 2001), depth to the base of the Ozark aquifer is roughly 1,750 feet below ground surface. Groundwater samples taken from lower Paleozoic aquifers in Kansas show TDS levels ranging from <500 to 5,000 mg/L (Figure A8-10) (Macfarlane and Hathaway, 1987), well within the range for a USDW.

Table A8-2 contains information concerning the relative location of potential USDWs and methane-bearing coalbeds in the Cherokee Basin. The table shows that the targeted coal seams could be coincident with a USDW, allowing the potential for impacts. Most coalbed methane activity within the Cherokee Basin historically took place in Kansas (Quarterly Review, 1993). However, coalbed methane production activity within the Cherokee Basin in Oklahoma has increased markedly in recent years (Hudson, OCC, personal communication 2001).

Table A8-2 Relative Locations of USDWs and Potential Methane-Bearing Coalbeds, Cherokee Basin

Coal Group	Kansas		Missouri		Oklahoma	
	Depth to top of Coal [1] (ft)	Depth to base of Fresh Water (USDW) [2] (ft)	Depth to top of Coal [1] (ft)	Depth to base of Fresh Water [3] (ft)	Depth to top of Coal [1] (ft)	Depth to base of Fresh Water (ft)
Mulky	600 to 1000	~ 1750	600 to 1000	N/A[4]	600 to 1000	N/A[4]
Weir-Pittsburg	800 to 1200		800 to 1200		800 to 1200	
Riverton	800 to 1200		800 to 1200		800 to 1200	

[1] Quarterly Review, 1993
[2] Ozark Aquifer extent and base, and Kansas elevation maps from the Kansas Data Access and Support Center (DASC) 2001
above
[3] Missouri's Geological Survey, Water Resources Branch, claims no water supplies in these strata
[4] Not Available

8.2.3 Forest City Basin USDW Identification

The Forest City Basin includes parts of the states of Iowa, Kansas, Missouri, and Nebraska. In Iowa, the Forest City Basin lies within the Southern Iowa Drift Plain physiographic province (Figure A8-11). The most productive aquifer in this area is the dolomite and sandstone Jordan aquifer (Figure A8-11). Wells in this aquifer commonly range in depth from 300 to 2,000 feet (some are as deep as 3,000 feet) and usually produce 100 to 1,000 gallons of water per minute (National Water Summary, 1984). This aquifer usually contains in excess of 1,500 mg/L TDS in the southern portion of the state (National Water Summary, 1984). Other aquifers used at various locations in the basin are found in the Silurian-Devonian age and in the Mississippian-age strata (Figure A8-11). Water wells in these aquifers range from 150 to 750 feet deep with variable production (Howes, IGSB, personal communication 2002). Also contained within this basin in Iowa is a portion of the confined, poorly-cemented sandstone Dakota aquifer (National Water Summary, 1984)(Figure A8-11). Water wells in this aquifer are typically 100 to 600 feet in depth, and commonly produce 100 to 250 gallons of water per minute (National Water Summary, 1984). An Iowa Division of Natural Resources Geological Survey Bureau geologist, Mary Howes, said that few towns in Iowa use Pennsylvanian strata for water, as they typically contain high concentrations of sulfate and total dissolved solids (Howes, IGSB, personal communication 2001). Most community water supplies in the southern portion of Iowa use surface water and shallow alluvial aquifers as drinking water sources, and there are a few wells in fractured bedrock. Private water supplies typically are derived from seepage wells, shallow bedrock wells, or purchased from a public supply (Howes, IGSB, personal communication 2002).

In Kansas, the basin is located in the Lowlands physiographic province (Figure A8-7), and only the northeastern corner of the state falls within the Forest City Basin boundary. In addition to the Douglas aquifers described above in the Cherokee Basin aquifer descriptions, this portion of the Forest City Basin in Kansas also contains a glacial drift aquifer and some alluvial aquifers adjacent to the Kansas River (National Water Summary, 1984) (Figure A8-7). In the glacial drift, wells are typically 10 to 300 feet in depth and usually produce 10 to 100 gallons of water per minute (National Water Summary, 1984). Wells are usually 10 to 150 feet deep in the alluvium and typically produce 10 to 500 gallons of water per minute (National Water Summary, 1984). The glacial drift aquifer's base varies from about 850 to 1,300 feet above sea level (DASC, Glacial Drift Base Map, 2001). Since the elevation of the land surface in this portion of Kansas is roughly from 1,000 to 1,400 feet above sea level (DASC, Kansas Elevation Map, 2001), the aquifer appears to extend only to about an approximate maximum depth of 150 feet below the ground surface.

In Missouri, the basin lies within the Central Lowland physiographic province (Figure A8-8). The principal aquifer in this area is a glacial-drift aquifer (Figure A8-8). In this aquifer, water wells are typically 100 to 250 feet in depth and produce 5 to 200 gallons of water per minute. In addition to this aquifer, alluvial deposits along the Missouri River are also developed for water (National Water Summary, 1984)(Figure A8-8). Well depths in the alluvium usually range from 80 to 100 feet in depth, and the wells typically produce 100 to 1,000 gallons of water per minute (National Water Summary, 1984). Two public supply wells in Cass County, Missouri, extract water from Pennsylvanian strata for the town of East Lynn. A map of ground water quality within Paleozoic aquifers of Missouri (Figure A8-12) shows that within the Forest City Basin, water quality ranges from about 500 mg/L TDS to 40,000 mg/L TDS in deeper portions of the basin (Missouri Division of Geological Survey and Water Resources, 1967). A 10,000 mg/L TDS boundary line delineated in the Mississippian aquifers of Missouri (located directly below Pennsylvanian-age strata) includes portions of Cass, Jackson, Lafayette, Carroll, Saline, Ray, Clay, Caldwell, Clinton, and Platte Counties (Netzler, 1982) (Figure A8-8).

Only the very southeastern tip (Richardson County primarily) of Nebraska falls within the limits of the Forest City Basin. The principal aquifers in this area are undifferentiated aquifers in Paleozoic-age rocks (National Water Summary, 1984)(Figure A8-13). Locally overlain by saturated Quaternary-age sand and gravel deposits, wells within this area are commonly 30 to 2,200 feet in depth, and commonly produce about 10 to 200 gallons of water per minute. Dissolved solids levels in the water can be as high as 6,000 mg/L, but are usually less than 1,500 mg/L (National Water Summary, 1984). The Ground Water Atlas of Nebraska (Flowerday et al, 1998) shows Richardson County to be within the Southeastern Nebraska Glacial Drift rock unit. The thickness of the aquifer in Richardson County is less than 100 feet and the depth to water is 30 to 200 feet. The information in the Ground Water Atlas of Nebraska (Flowerday et al, 1998) appears to be in conflict with the data presented by the USGS in the National Water Summary (1984). Matt Jokel of the state's Conservation and Survey Division said it is very hard to obtain water in this portion of the state, and most people use valley fill materials and paleochannels as water supply sources. He also believes that the coal resources, which could possibly be used for methane extraction, are probably too deep to be located coincident with the shallow water supplies in the area (Jokel, NCSD, personal communication 2001).

Table A8-3 contains information concerning the relative location of potential USDWs and potential methane-bearing coalbeds in the Forest City Basin.

Table A8-3 Relative Locations of USDWs and Potential Methane-Bearing Coalbeds, Forest City Basin

Coal Group	Iowa		Kansas		Missouri		Nebraska	
	Depth to top of Coal [1] (ft)	Depth to base of fresh water[3] (ft)	Depth to top of Coal [1] (ft)	Depth to base of fresh water [4] (ft)	Depth to top of Coal [1] (ft)	Depth to base of fresh water [5] (ft)	Depth to top of Coal[1,6] (ft)	Depth to base of fresh water [2,7] (ft)
Cherokee Group	0 to >230	N/A[8]	720 to 1220	~ 150	300 to 1100	N/A[8]	1220 to 1396	129 to 299

[1] Bostic et al., 1993
[2] Note: The base of "fresh water" is not the base of the USDW. Fresh water is within the USDW and the base of fresh water is above the base of the USDW.
[3] Iowa Geological Survey Bureau (2001) believes water quality data may be available to define this depth
[4] Glacial Drift base and Kansas elevation maps from the Kansas Data Access and Support Center (DASC), 2001
[5] Maps (Netzler, 1982) sent by Missouri show the extent of aquifers containing less than 10,000 mg/L of TDS, but not depths
[6] Condra and Reed, 1959
[7] The Groundwater Atlas of Nebraska, (Flowerday et al, 1998)
[8] Not Available

Presently, there does not appear to be a USDW located within the coals of the Cherokee Group in the Forest City Basin. However, very little is known about the coal resources of the basin (Quarterly Review, 1993). Further in-depth research is required to fully delineate the possible linkage between coalbed methane resources and USDWs in the Forest City Basin.

8.3 Coalbed Methane Production Activity

GTI places total coalbed gas production in the Western Interior Coal region at 6.5 billion cubic feet for the year 2000 (GTI, 2002).

8.3.1 Arkoma Basin Production Activity

Bear Production Company, in 1989, was the first company to target coalbed methane production from the Hartshorne Coals of the Arkoma Basin in Haskell County, Oklahoma (Quarterly Review, 1993). As of 1993, Bear Production had 38 wells in operation, Aztec Energy Corporation had 19 wells, and Redwine Resources, Inc. had 40 wells (Quarterly Review, 1993).

Bear Production (as of 1993) was not fracturing their wells, but rather completing them as open holes without perforated casings (Quarterly Review, 1993). However, other production companies were fracturing their wells for methane production. Before 1992, water, linear gel, acid, and nitrogen foam fracturing fluids were used, with most operators using foam with small sand volumes (35,000 to 60,000 lbs.) (Quarterly Review, 1993). In 1993, slick water fracturing fluids containing no proppant were becoming more common (Quarterly Review, 1993). Well fracturing data from 36 wells in the Spiro Southeast Field of LeFlore County, Oklahoma show that either water or nitrogen foam was the base fracturing fluid used to carry sand proppant into coal cleats (Andrews et al., 1998). Fracturing continues in the Arkoma Basin today, at least in Oklahoma, where undisclosed amounts of initial water production are "frac" waters introduced during fracture stimulation (Cardott, 2001). Both Wendell (2001) and Marshall (2001) outline current hydraulic fracturing practices within the Arkoma Basin, and Wendell (2001) includes acids, benzene, xylene, toluene, gasoline, diesel, solvents, bleach, and surfactants as detrimental hydraulic fracturing substances in his "lessons learned" category.

A search of the Oklahoma Coal Database, updated on January 17, 2001, indicated that over 360 coalbed methane wells had been completed in Haskell, Le Flore, and Pittsburg counties alone, targeting the Hartshorne, McAlester, and Savanna coals. Additional operators in the Arkoma Basin today include Continental Resources, SJM Inc., Brower O & G, Mannix Oil, and OGP Operating (Oklahoma Coal Database, 2001).

Apparently there is little to no coalbed methane activity in the Arkoma Basin in Arkansas, based on the Arkansas Geological Commission's website, which states "…there exists the potential for coalbed methane production in this area of the state" (http://www.state.ar.us/agc.htm). This is further confirmed by Andrews et al. (1998), which outlines Arkansas' restrictive field-spacing policy from the 1930's of only one well per 640-acre section for each producing zone in the Hartshorne. This policy effectively made exploration uneconomical. A change in field-spacing rules in 1995 has stimulated new interest among independent producers in Arkansas to develop methane from the Hartshorne coals (Andrews et al., 1998).

8.3.2 Cherokee Basin Production Activity

In the Cherokee Basin, unknown amounts of coalbed methane gas have been produced with conventional natural gas for over 50 years (Quarterly Review, 1993). Targeted coalbed methane production increased in the late 1980s, and at least 232 coalbed methane wells had been completed as of January 1993 (Quarterly Review, 1993). During this timeframe, development was centered on Montgomery County, Kansas, with the most active operators being Great Eastern Energy and Development Corporation (81 wells), Kan Map Inc. (47 wells), and Stroud Oil Properties Inc. (35 wells), which has developed the Sycamore Valley field (Quarterly Review, 1993). In addition to these operators, Bonanza Energy Corporation, Conquest Oil Company, Foster Oil & Gas, Hunter, Quantum Energy, Uranus, and U.S. Exploration had active development programs, and Derrick Industries was planning a program (Quarterly Review, 1993).

The coalbed methane wells were typically fractured with water or nitrogen-based fluids and sand, although the shallower Mulky coal received fracturing treatments of 40-pound linear gel and sand (Quarterly Review, 1993). On average, 5,000 pounds of sand were used per foot of coal (Quarterly Review, 1993). Another technique used in Kansas consists of four barrels of 15% hydrochloric acid mixed with 16 barrels of potassium chloride and 15,000 standard cubic feet of nitrogen (Stoeckinger, 1990). In the Sycamore Valley field in Kansas, Stroud Oil Properties used 426 barrels of cross-linked fluid with 52% pad and 3% flush, and 30,000 lb. of 12/20 sand mixed at one to nine pounds per gallon injected at 20 barrels per minute. Operators were avoiding large-volume treatments due to a fear that fractures could be induced in thick water-bearing sands above and below the coals, which would have created excess fracturing fluid production (Quarterly Review, 1993). Stoeckinger (2000) reports that current hydraulic fracturing practices in the Cherokee Basin in Kansas are water only, no gel, with nitrogen being "popular" and "slick-water down tubing."

Pam Hudson, of the Oklahoma Corporation Commission, indicated that coalbed methane extraction was beginning to grow in the Cherokee Basin in the northeastern section of Oklahoma, and more development was now centered on that region versus the Arkoma Basin to the south. Ms. Hudson expected that much of the development would be focused on Washington, Nowata, and Craig Counties (Hudson, OCC, personal communication 2001).

In Missouri, there appears to be very little to no coalbed methane extraction within the Cherokee Basin. David Smith, a geologist with the state's geological survey, states that coalbed methane extraction in Missouri is essentially non-existent (Smith, MGS, personal communication 2001).

8.3.3 Forest City Basin Production Activity

The Forest City Basin was relatively unexplored in 1993, with about ten coalbed wells concentrated in Atchison, Jefferson, Miami, Leavenworth, and Franklin Counties, Kansas

(Quarterly Review, 1993). The wells were hydraulically fractured with 500 to 30,000 pounds of sand proppant, averaging being 5,000 pounds. Fluids used during the fracturing process were not mentioned (Quarterly Review, 1993).

David Smith, a geologist with the Missouri Geological Survey, believes there were some coalbed methane wells in Cass County (just south of Kansas City) at one time (Smith, MGS, personal communication 2001). Sherri Stoner, of the Missouri Geological Survey, confirmed this in February 2001, and said that they were no longer in operation (Stoner, MGS, personal communication 2001). An Iowa Division of Natural Resources Geological Survey Bureau geologist, Mary Howes, stated that presently there was no coalbed methane production in Iowa (Howes, IDNRB, personal communication 2001).

Information concerning coalbed methane production activity in Iowa and Nebraska could not be found.

8.4 Summary

In the Arkoma Basin, based on depths to the Hartshorne Coal and the base of fresh water presented in Table A8-1, it appears that coalbed methane extraction wells could be coincident with potential USDWs in Arkansas, potentially allowing for impacts. Based on maps provided by the Oklahoma Corporation Commission (2001) as to the depths of the 10,000 mg/L of TDS ground water quality boundary in Oklahoma, the location of coalbed methane wells and USDWs would most likely not coincide in Oklahoma. This is based on depths to coals typically greater than 1,000 feet (Andrews et al, 1998) and depths to the base of the USDW typically shallower than 900 feet (OCC Depth to Base of Treatable Water Map Series, 2001).

Table A8-2 supports the possibility that coalbed methane wells in the Cherokee Basin targeting the Cherokee Group coals in Kansas may coincide with USDWs, indicating the potential for impacts. In Missouri, more water quality data is required prior to any determination of coalbed methane well/USDW conflict. In addition, since only a very small portion of the Cherokee Basin falls within the state, this portion of the basin needs to be delineated more precisely to see which USDWs lie within this small part of the basin. However, current levels of coalbed methane activity in Missouri are minimal.

Lastly, in the Forest City Basin, there appears to be little physical relationship between coalbeds that may be used for coalbed methane extraction and water supplies. However, aquifer and well information from the National Water Summary (1984) indicates that a co-location of the two could exist in Iowa and Nebraska. Clearly, more information will be needed to fully investigate the relationship between coalbeds and USDWs in the Forest City Basin.

REFERENCES

Andrews, Richard D., Cardott, Brian J., and Storm, Taylor. 1998. The Hartshorne Play in Southeastern Oklahoma: regional and detailed sandstone reservoir analysis and coalbed-methane resources. Oklahoma Geological Survey, Special Publication 98-7.

Arkansas Geological Commission website, 2001. http://www.state.ar.us/agc.htm

Bostic, Joy L., Brady, L. L., Howes, M. R., Burchett, R. R., and Pierce, B. S. 1993. Investigation of the coal properties and the potential for coal-bed methane in the Forest City Basin. U. S. Geological Survey, Open File Report 93-576.

Brady, L. L. 2002. Kansas Geological Survey, *personal communication*.

Burchett, Raymond R. No date specified. Coalbed methane potential in the Nebraska portion of the Forest City Basin. Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln.

Cardott, Brian J. 2001. Coalbed -Methane Activity in Oklahoma, 2001. Oklahoma Coalbed-Methane Workshop 2001: Oklahoma Geological Survey, Open File Report 2-2001, p. 93-118.

Charpentier, Ronald R. 1995. Cherokee Platform Province. U. S. Geological Survey, National Assessment of United States Oil and Gas Resources.

Condra, G. E. and Reed, E. C. 1959. The geological section of Nebraska. Nebraska Geological Survey Bulletin 14A, 1959.

Cordova, Robert M. 1963. Reconnaissance of the ground-water resources of the Arkansas Valley Region, Arkansas. Contributions to the Hydrology of the United States, Geological Survey Water-Supply Paper 1669-BB.

DASC website. 2001. Glacial drift base map. http://gisdasc.kgs.ukans.edu/dasc/kanview.html

DASC website. 2001. Kansas elevation map http://gisdasc.kgs.ukans.edu/dasc/kanview.html

DASC website. 2001. Ozark Aquifer base map. http://gisdasc.kgs.ukans.edu/dasc/kanview.html

DASC website. 2001. Ozark Aquifer extent map. http://gisdasc.kgs.ukans.edu/dasc/kanview.html

Flowerday, C. F., Kuzelka, R. D., and Pederson, D. T., compilers. 1998. The Ground Water Atlas of Nebraska.

Friedman, Samuel A. 1982. Determination of reserves of methane from coalbeds for use in rural communities in eastern Oklahoma. Oklahoma Geological Survey, Special Publication 82-3, 1982.

Gas Technology Institute (GTI) website, 2002. Drilling and Production Statistics for Major US Coalbed Methane and Gas Shale Reservoirs. http://www.gastechnology.org

Hansen, D. 2001. Arkansas Geological Commission, *personal communication.*

Howes, M. R. 2001. Iowa Geological Survey Bureau, *personal communication.*

Howes, M. R. 2002. Iowa Geological Survey Bureau, *personal communication.*

Hudson, P. 2001. Oklahoma Corporation Commission, *personal communication.*

Jokel, M. 2001. Nebraska Conservation and Survey Division, *personal communication.*

Luza, K. 2001. Oklahoma Geological Survey, *personal communication.*

Macfarlane, A. 2001. Kansas Geological Survey, *personal communication.*

Macfarlane, P. A. and Hathaway, L. R. 1987. The Hydrologic and Chemical Quality of Ground Waters from the Lower Paleozoic Aquifers in the Tri-State Region of Kansas, Missouri, and Oklahoma: Kansas Geological Survey Groundwater Series 9.

Marcher, M. V. 1969. Reconnaissance of the Water Resources of the Fort Smith Quadrangle, East-Central Oklahoma: Oklahoma Geological Survey Hydrologic Atlas 1.

Marcher, M. V. and Bingham 1971. Reconnaissance of the Water Resources of the Tulsa Quadrangle, Northeastern Oklahoma: Oklahoma Geological Survey Hydrologic Atlas 2.

Marshall, R. 2001. Midcontinent Evolving Coalbed-Methane Completion Techniques and Practices. Oklahoma Coalbed-Methane Workshop 2001: Oklahoma Geological Survey, Open File Report 2-2001, p. 140-150.

Missouri Division of Geological Survey and Water Resources. 1967. Mineral & Water Resources of Missouri, 43(2).

Nelson, Charles R. 1999. Changing perceptions regarding the size and production potential of coalbed methane resources. Gas Research Institute, June 1999.

Netzler, Bruce W. 1982. Maps of total dissolved solids concentrations in ground water from the Mississippian aquifers, the Jefferson City, Cotter and Powell Dolomites, and the Roubidoux Formation in Missouri.

National Water Summary. 1984. Hydrologic events, selected water-quality trends, and ground-water resources. United States Geological Survey Water-Supply Paper No. 2275.

Oklahoma Coal Database, January 17, 2001.

Oklahoma Corporation Commission, Depth to Base of Treatable Water Map Series, 2001.

Oklahoma Geological Survey website. 2001. http://www.ou.edu/special/ogs-pttc

Petroleum Technology Transfer Council website. 1999. http://www.pttc.org

Potts, Ronald. 1987. Water Quality and Quantity in Abandoned Underground Coal Mines of West-Central Arkansas and Use of Surface Electrical Resistivity in Attempting Quality Determinations. Arkansas Geological Commission - Information Circular 20-N.

Prior, W. 2001. Arkansas Geological Commission, *personal communication.*

Quarterly Review. 1993. Coalbed Methane – State of the Industry. Methane From Coal Seams Technology, August 1993.

Stoeckinger, William T. 1990. Kansas coalbed methane comes on stream. Oil & Gas Journal, June 4, 1990.

Stoeckinger, William T. 2000. Coalbed Methane Completion Practices on the Cherokee Platform. Oklahoma Coalbed-Methane Workshop: Oklahoma Geological Survey, Open-File Report OF 2-2000, p. 36-51.

Smith, D. 2001. Missouri Geological Survey, *personal communication.*

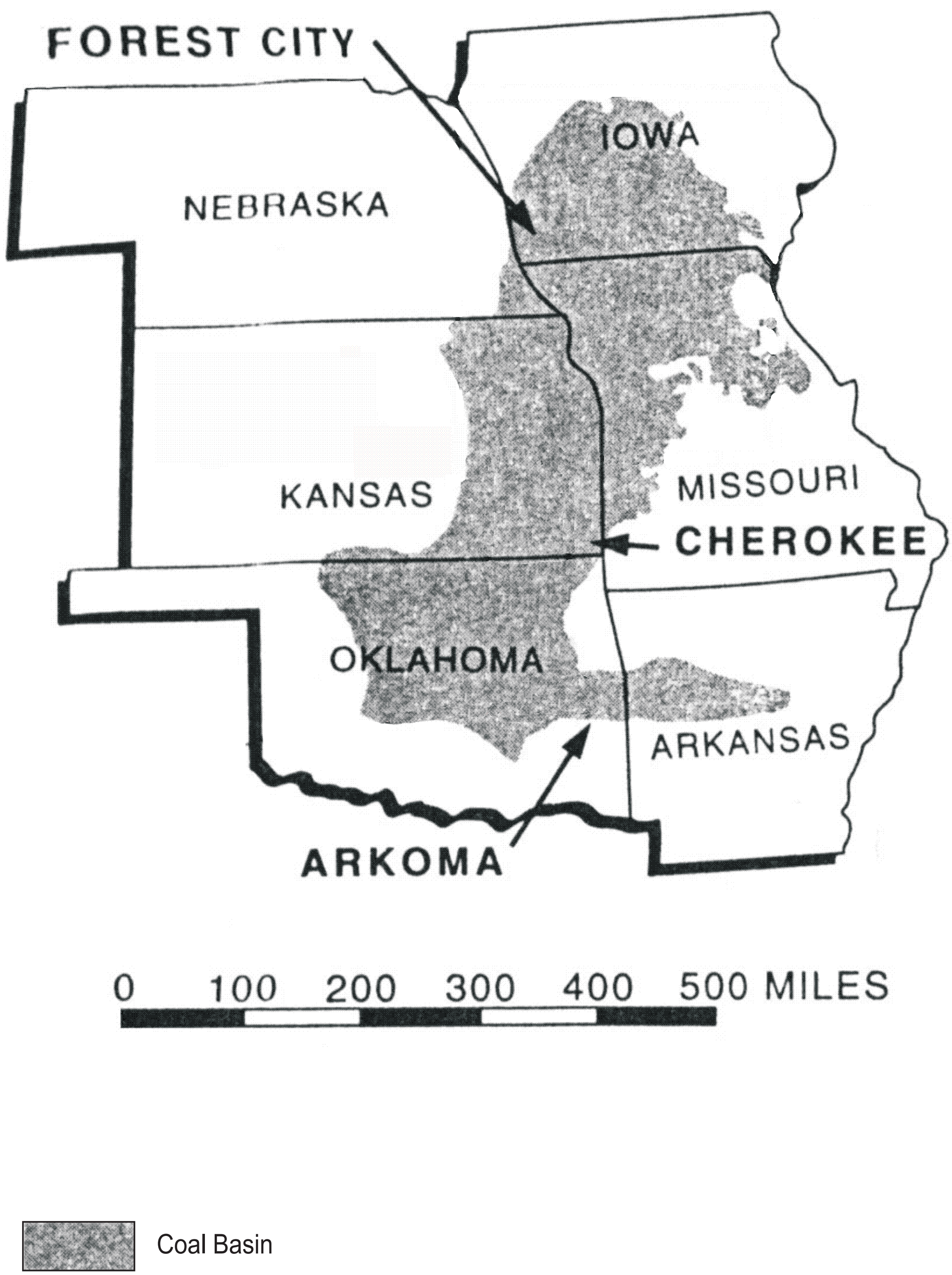
Smith, D. 2002. Missouri Geological Survey, *personal communication.*

Stoner, S. 2001. Missouri Geological Survey, *personal communication.*

Tedesco, Steven A. 1992. Coalbed methane potential assessed in Forest City Basin. Oil & Gas Journal, Exploration, February 10, 1992.

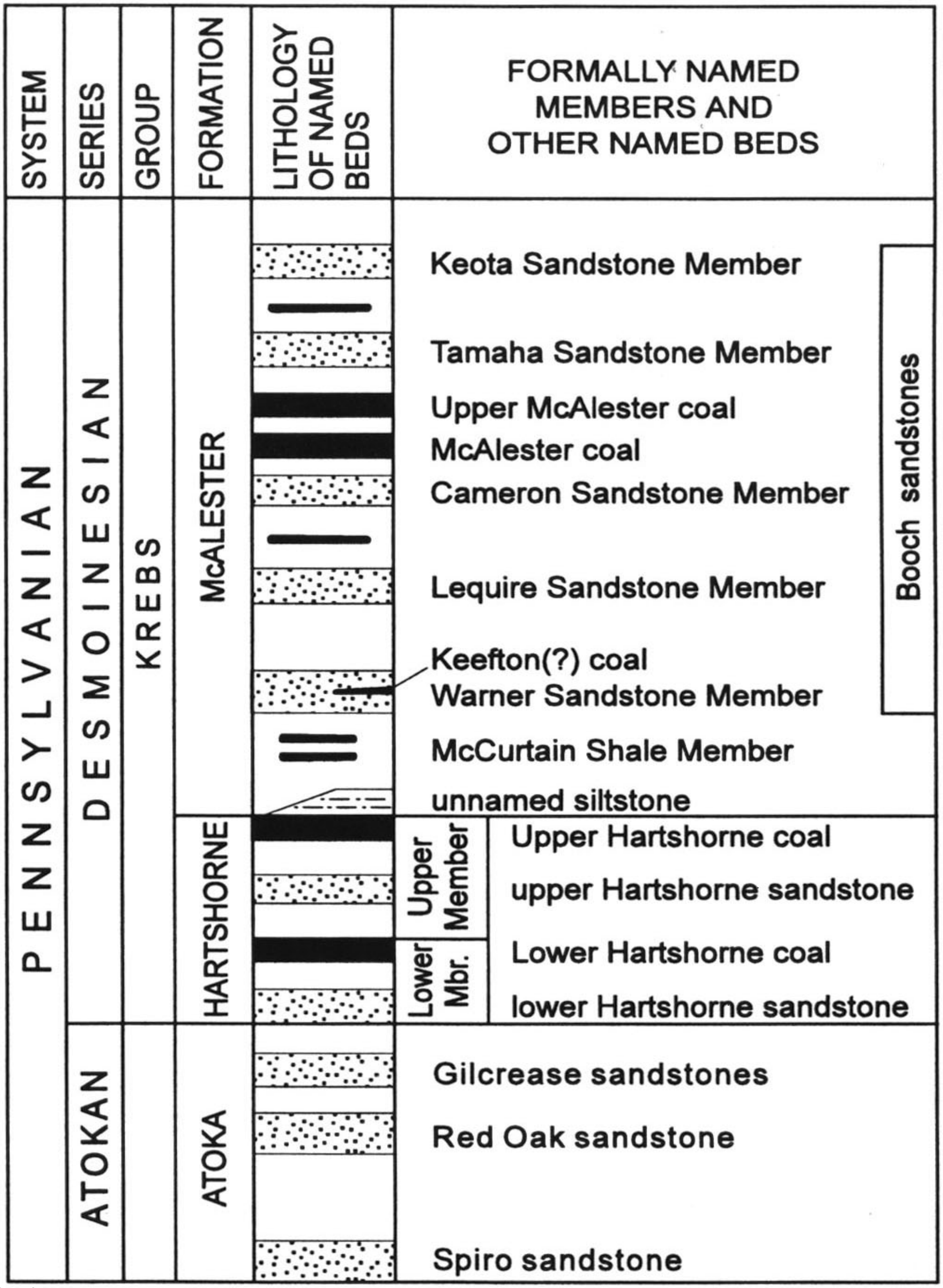
Vandike, J. 2001. Missouri Geological Survey, *personal communication.*

Wendell, John H. JR. 2001. Arkoma Basin Coalbed-Methane Potential and Practices. Oklahoma Coalbed-Methane Workshop 2001: Oklahoma Geological Survey, Open File Report 2-2001, p. 119-139.



Western Interior Coal Basin - Index Map of the Arkoma, Cherokee and Forest City Basins
(Quarterly Review, 1993)

7/14/01 kk 1027-WI-1.cdr	Figure A8-1



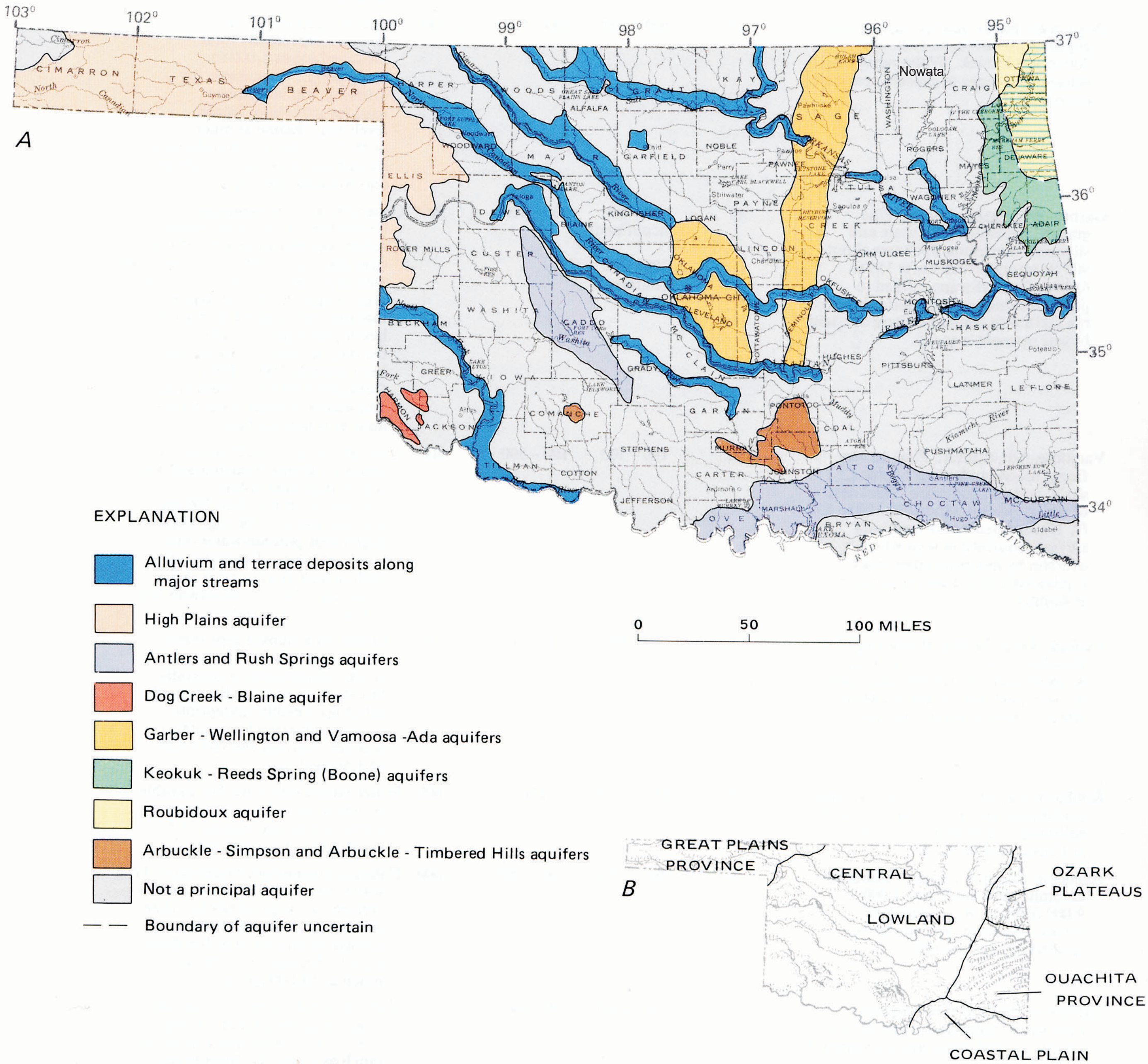
Mbr. = Member

Western Interior Coal Basin - Generalized Stratigraphic Column of the Pennsylvanian System

In the Arkoma Basin (Friedman, 1982)

5/29/02 kk 1027-WI-2.cdr

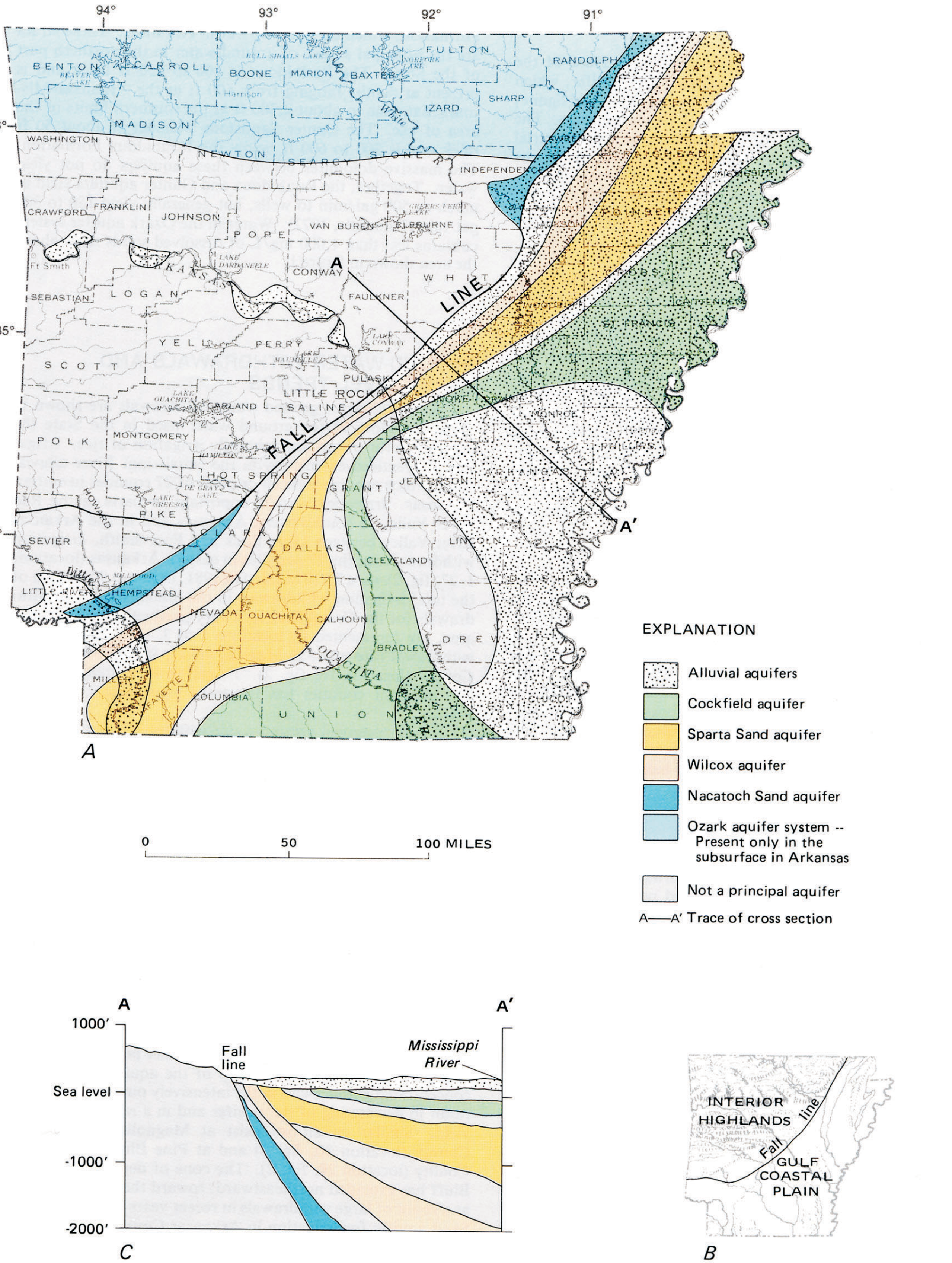
Figure A8-2



Counties, Aquifers, and Physiographic Provinces of Oklahoma

(National Water Summary, 1984)

5/29/02 kk 1027-WI-6.cdr	Figure A8-6

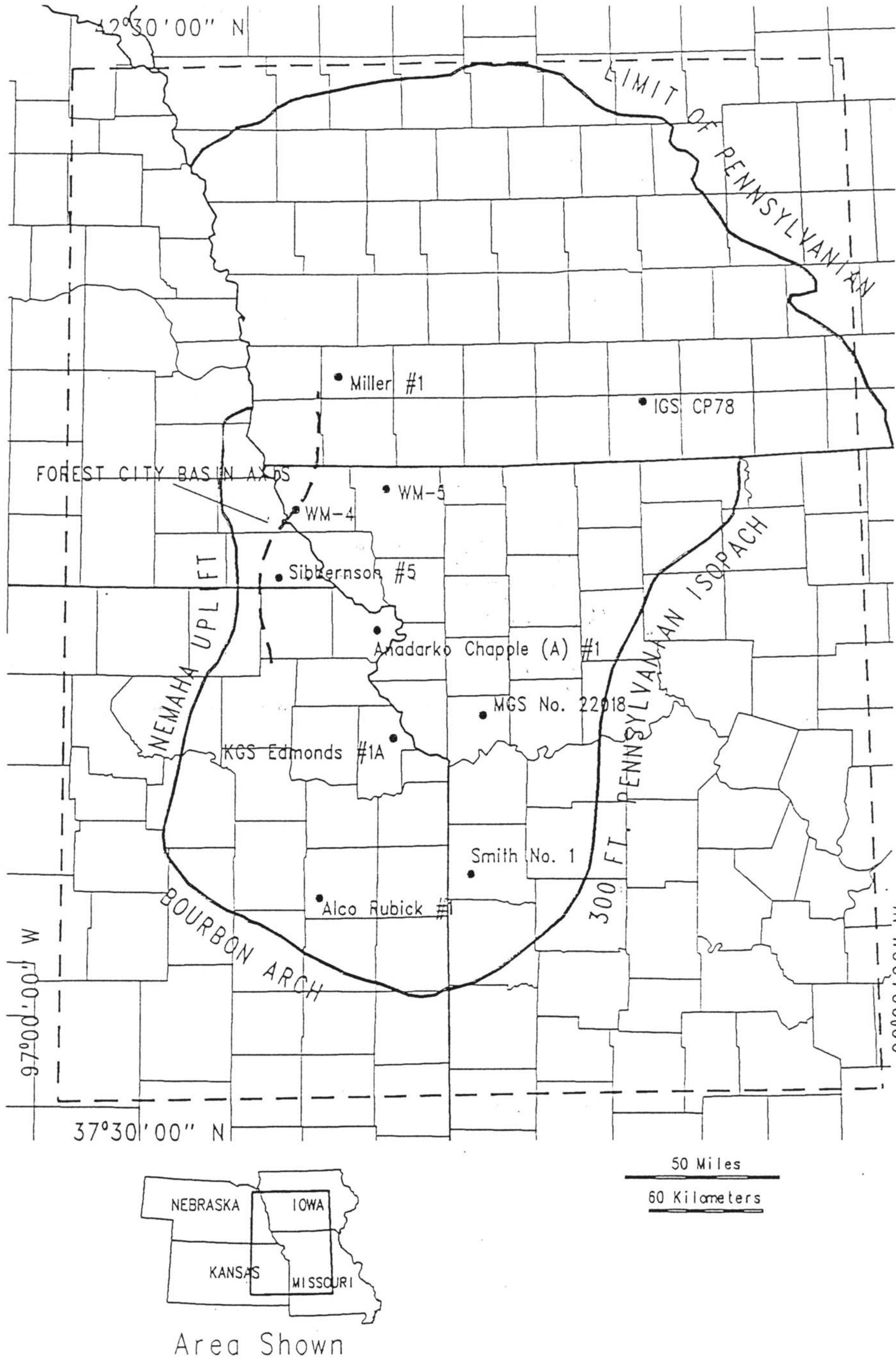


Counties, Aquifer, and Physiographic Provinces of Arkansas

(National Water Summary, 1984)

5/29/02 kk 1027-WI-5.cdr

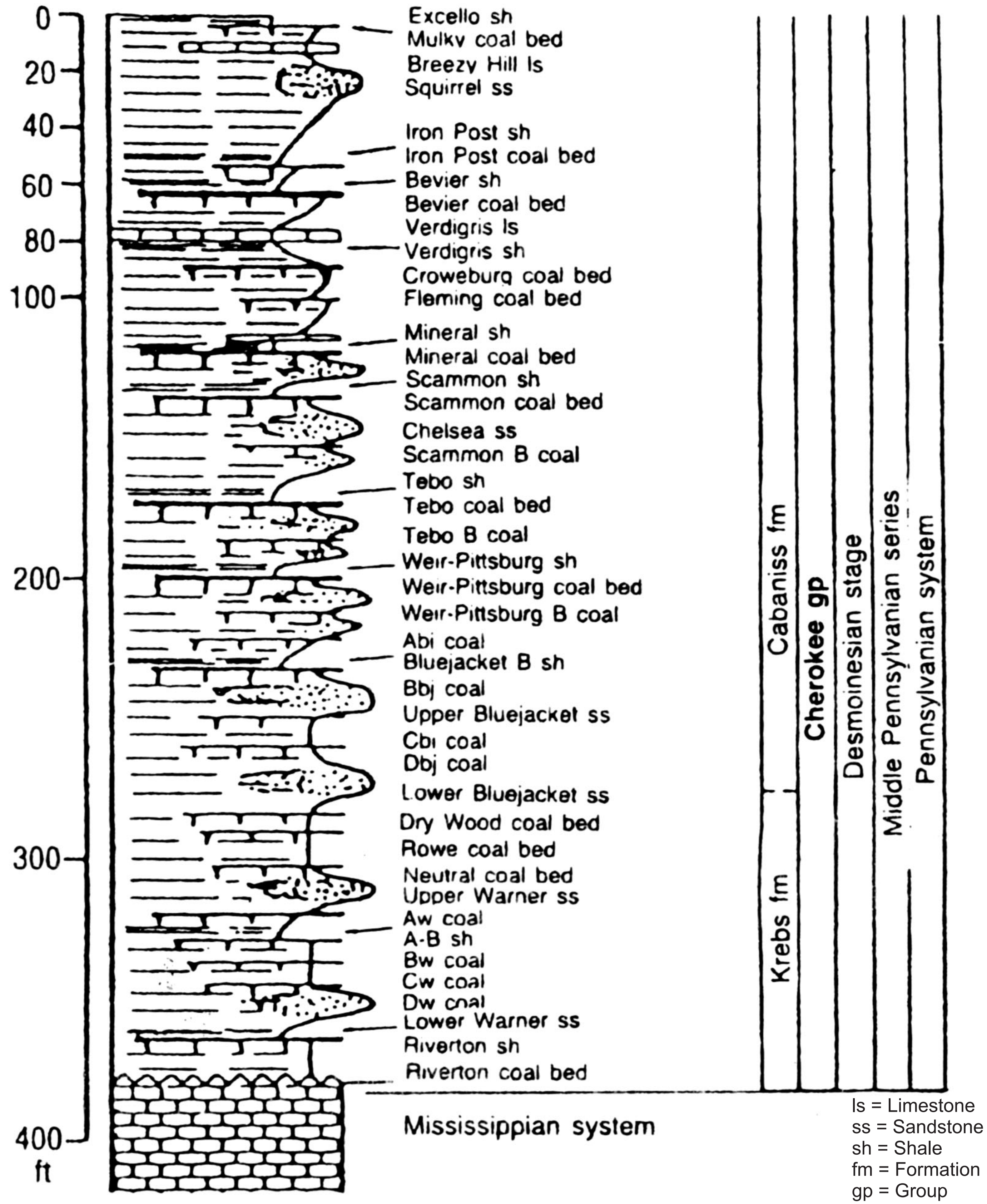
Figure A8-5



Western Interior Coal Basin - Forest City Basin Study Area
(Showing Location of Drill Holes Discussed in Bostic et al., 1993)

7/14/01 kk 1027-WI-4.cdr

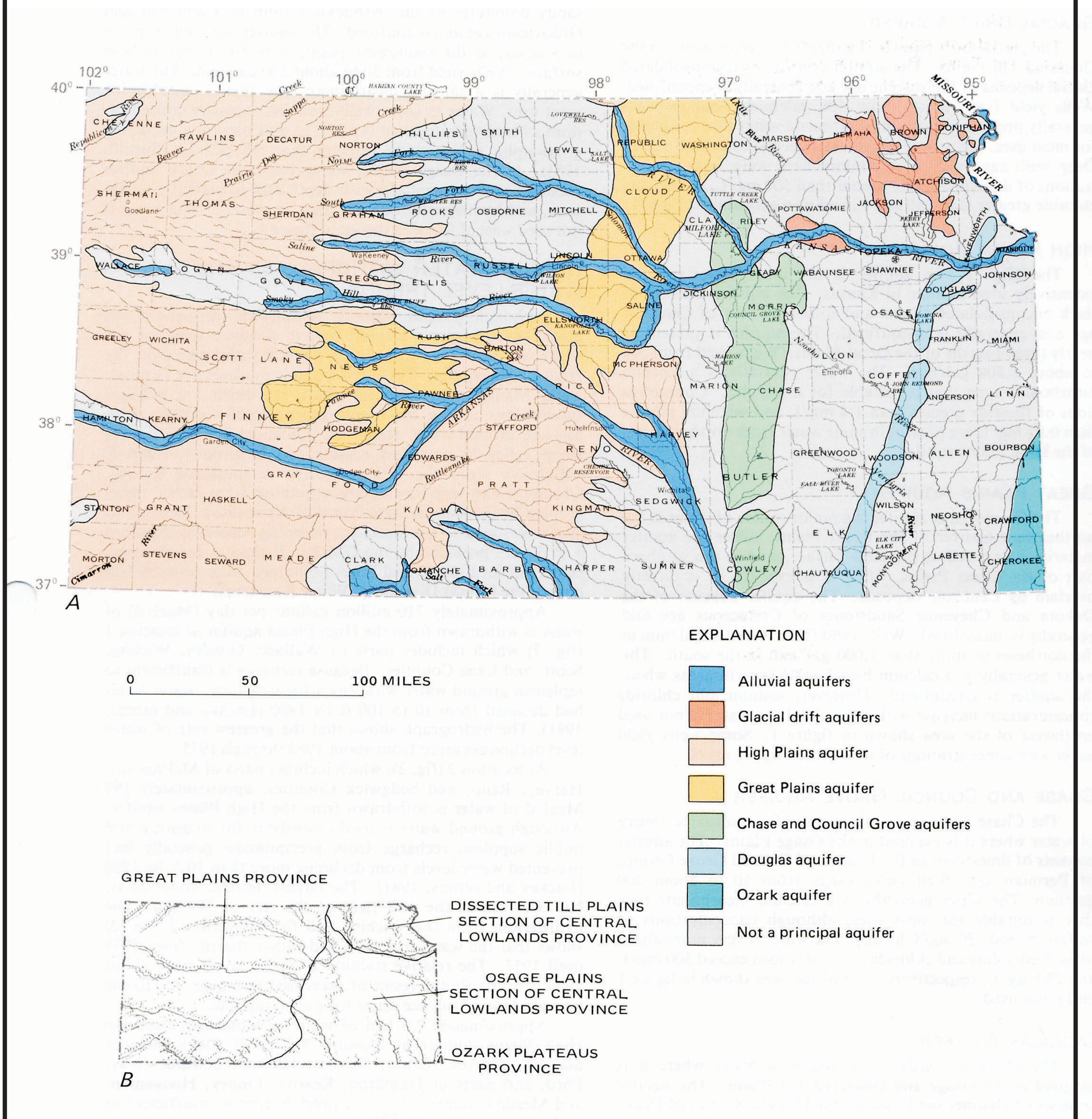
Figure A8-4



Western Interior Coal Basin - Stratigraphic Column of the Cherokee Group
In the Cherokee Basin (Tedesco, 1992)

5/29/02 1027-WI-3.cdr

Figure A8-3

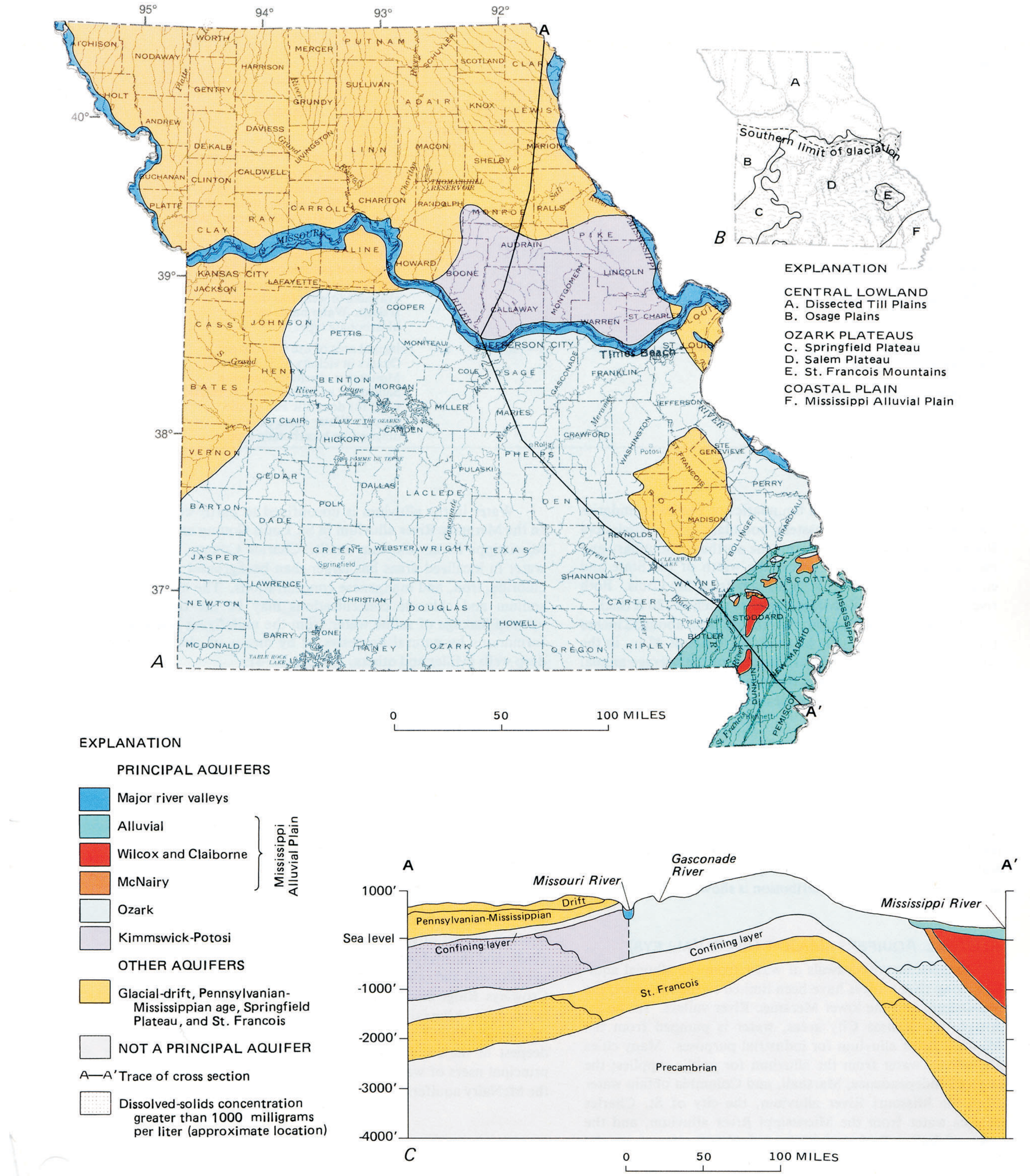


Counties, Aquifers, and Physiographic Provinces of Kansas

(National Water Summary, 1984)

5/29/02 kk 1027-WI-7.cdr

Figure A8-7

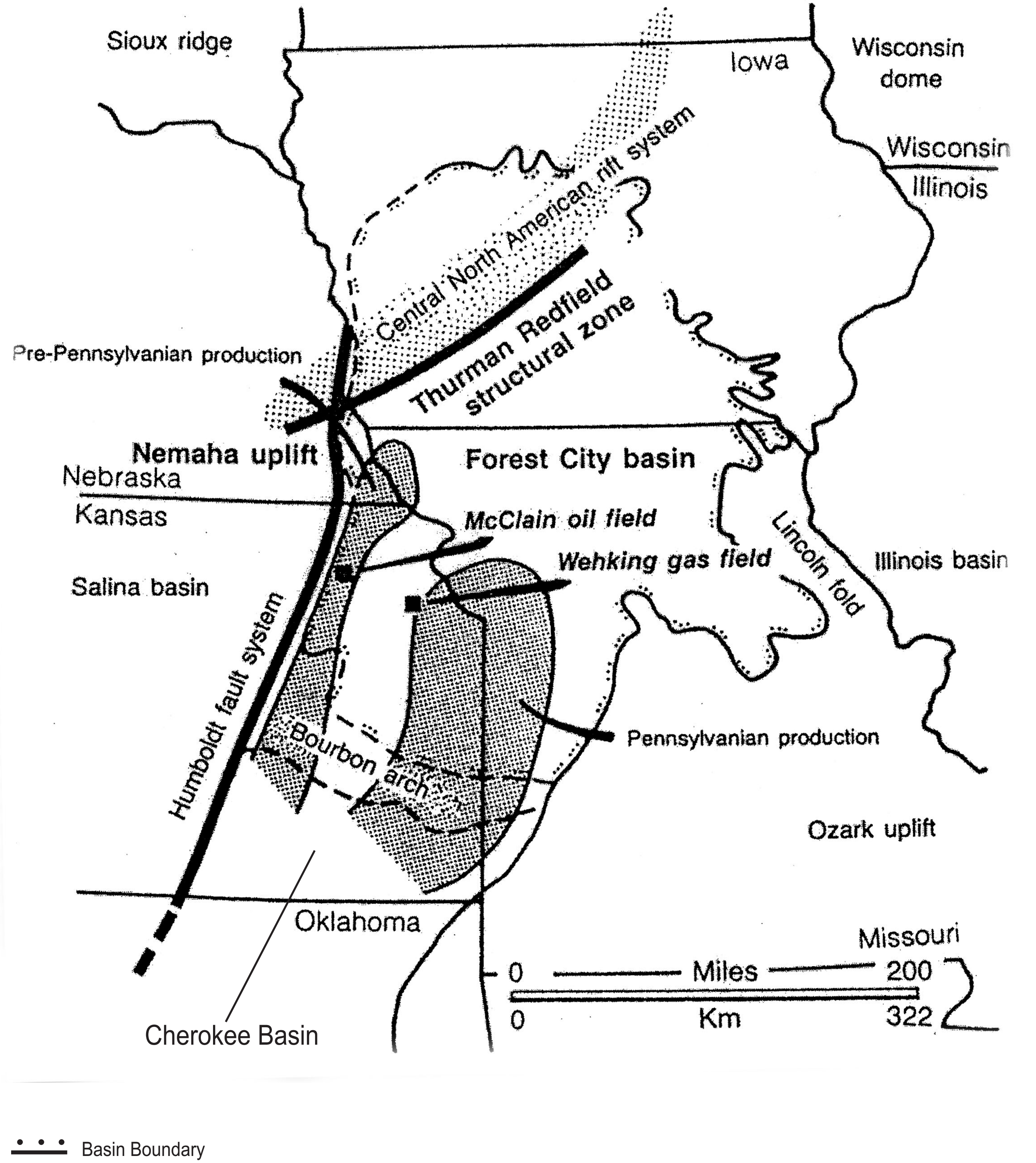


Counties, Aquifers, and Physiographic Provinces of Missouri

(National Water Summary, 1984)

5/29/02 kk 1027-WI-8.cdr

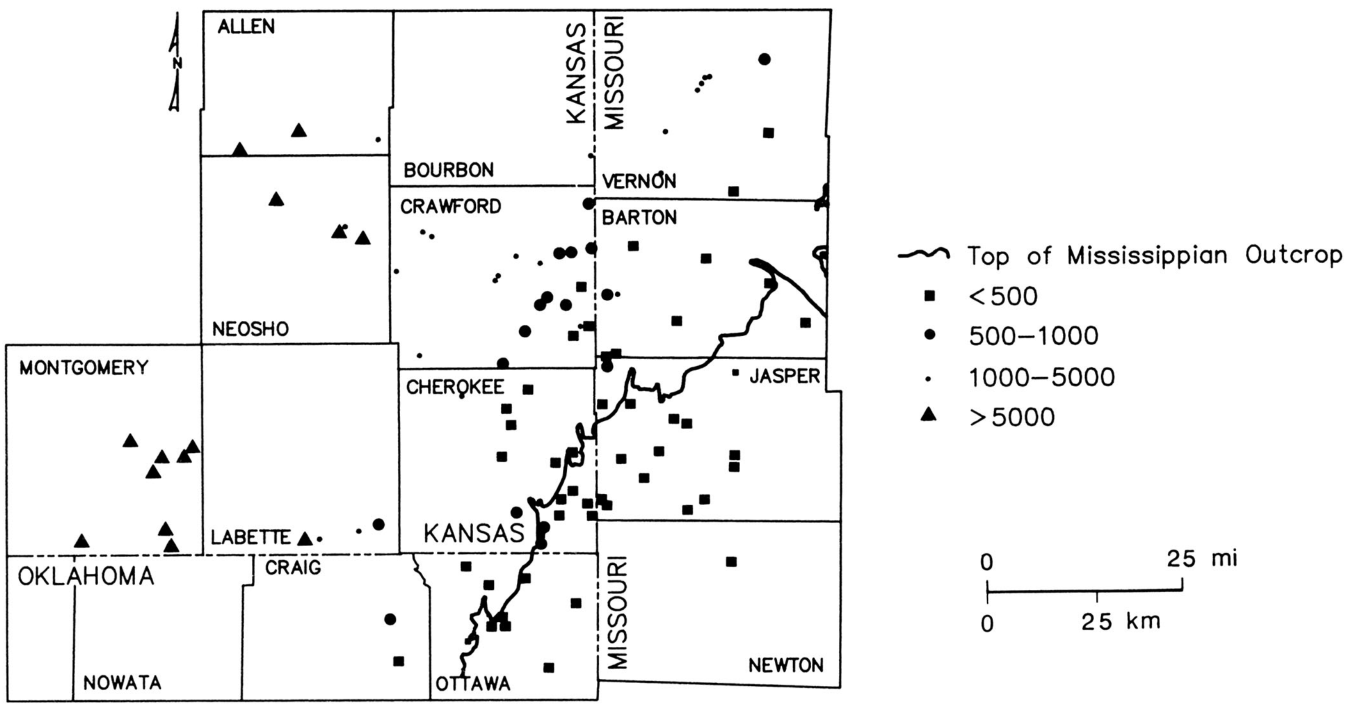
Figure A8-8



Western Interior - Detail of Forest City Basin with Detail of Cherokee Basin in Missouri (Tedesco, 1992)

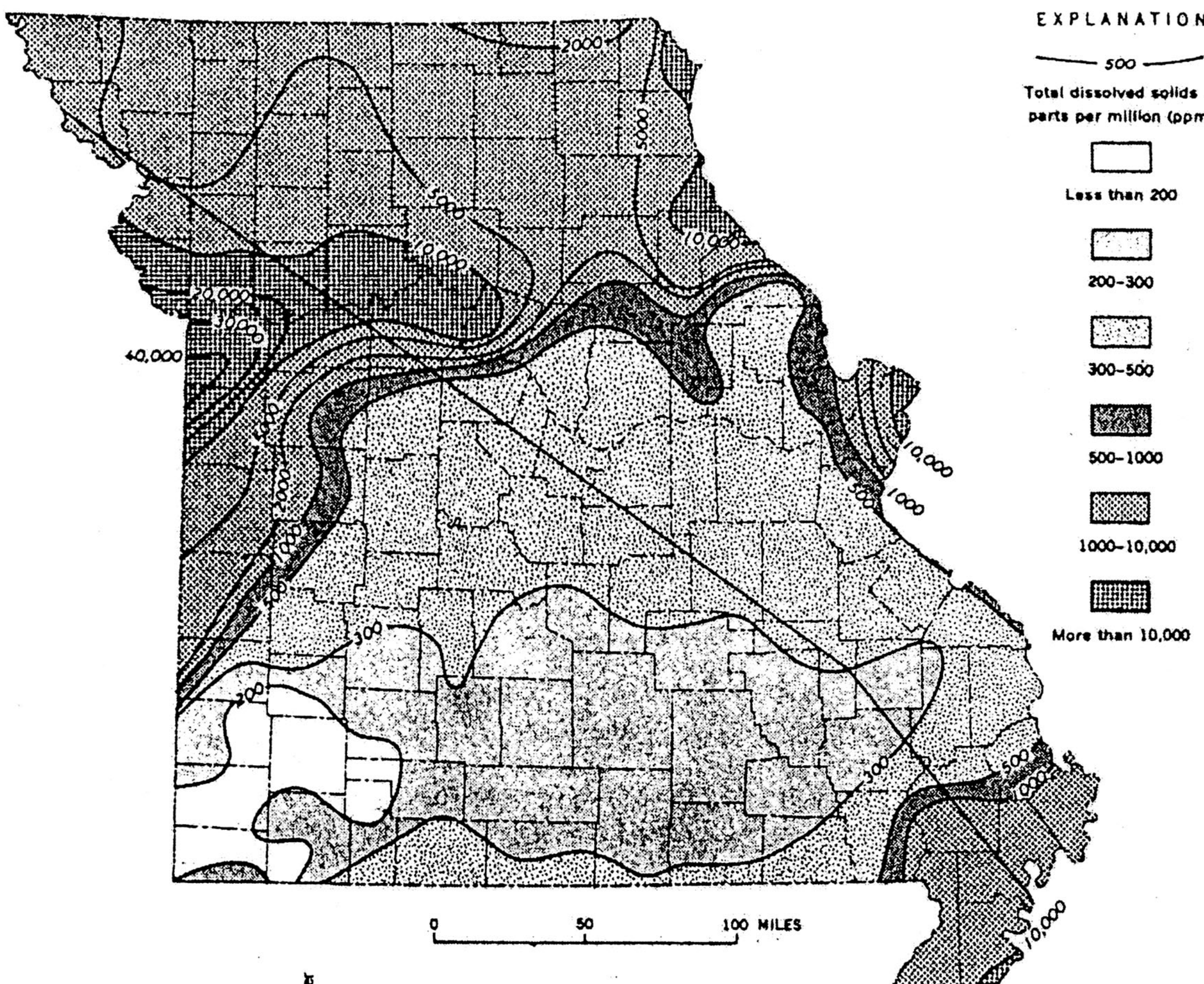
5/29/02 kk 1027-WI-9.cdr

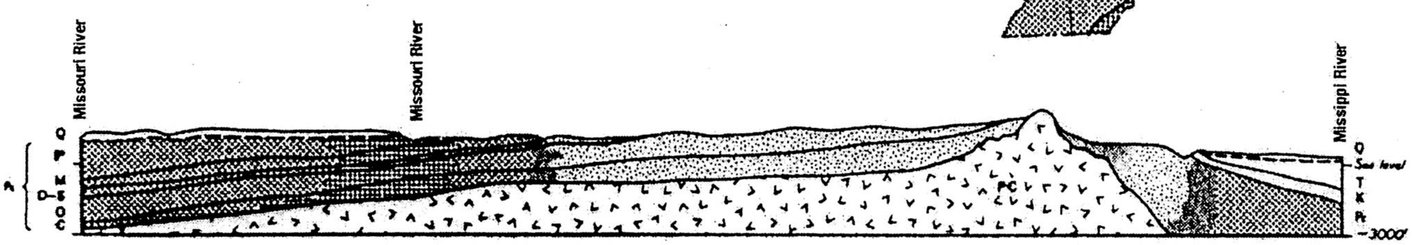
Figure A8-9



Water Quality (TDS) of Lower Paleozoic Aquifers in Kansas
(Macfarlane and Hathaway, 1987)

5/29/02 kk 1027-WI-10.cdr	Figure A8-10

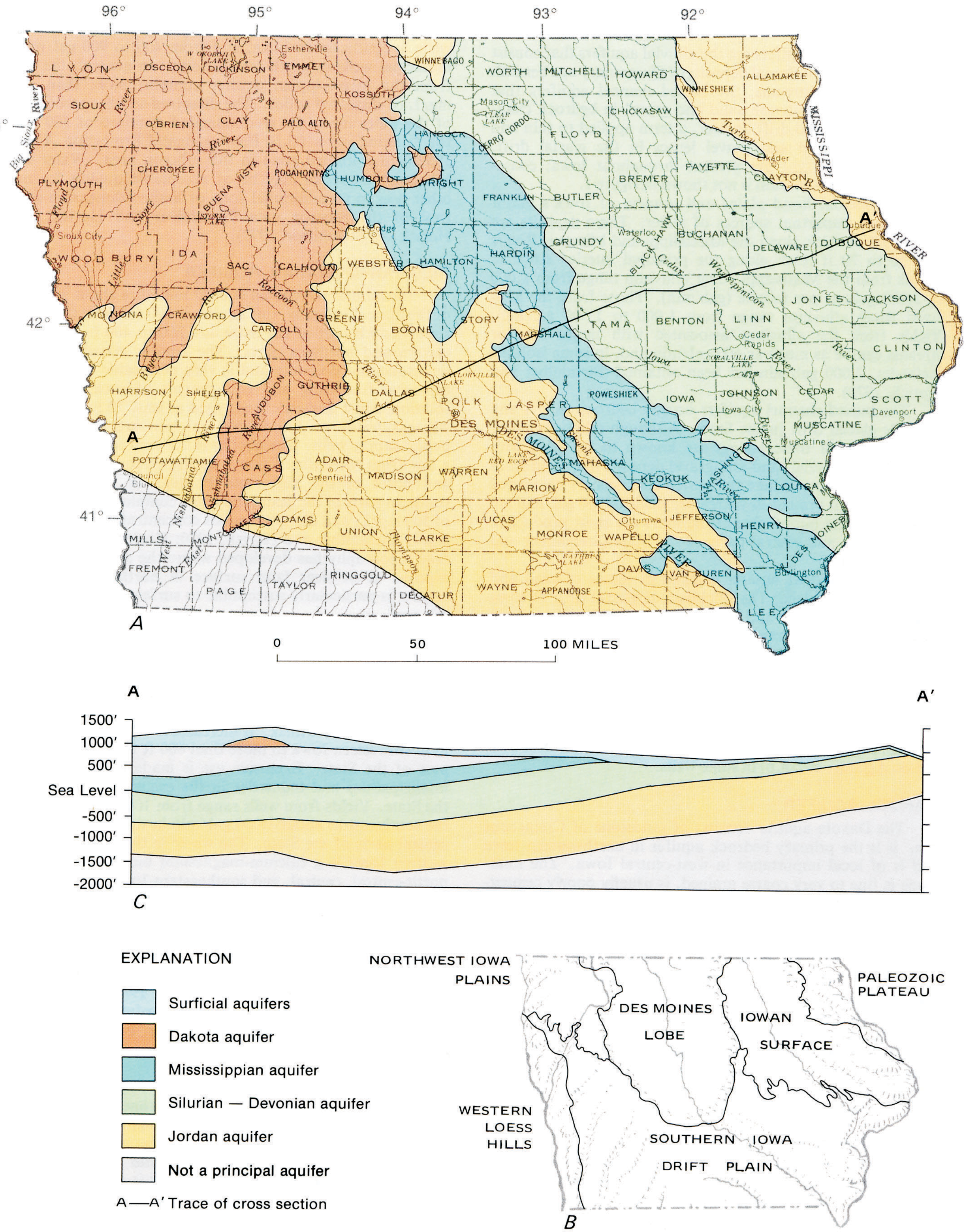




Western Interior Coal Basin - Quality of Ground water in the Palezoic Aquifers of Missouri

(Missouri Division of Geological Survey & Water Resources, 1967)

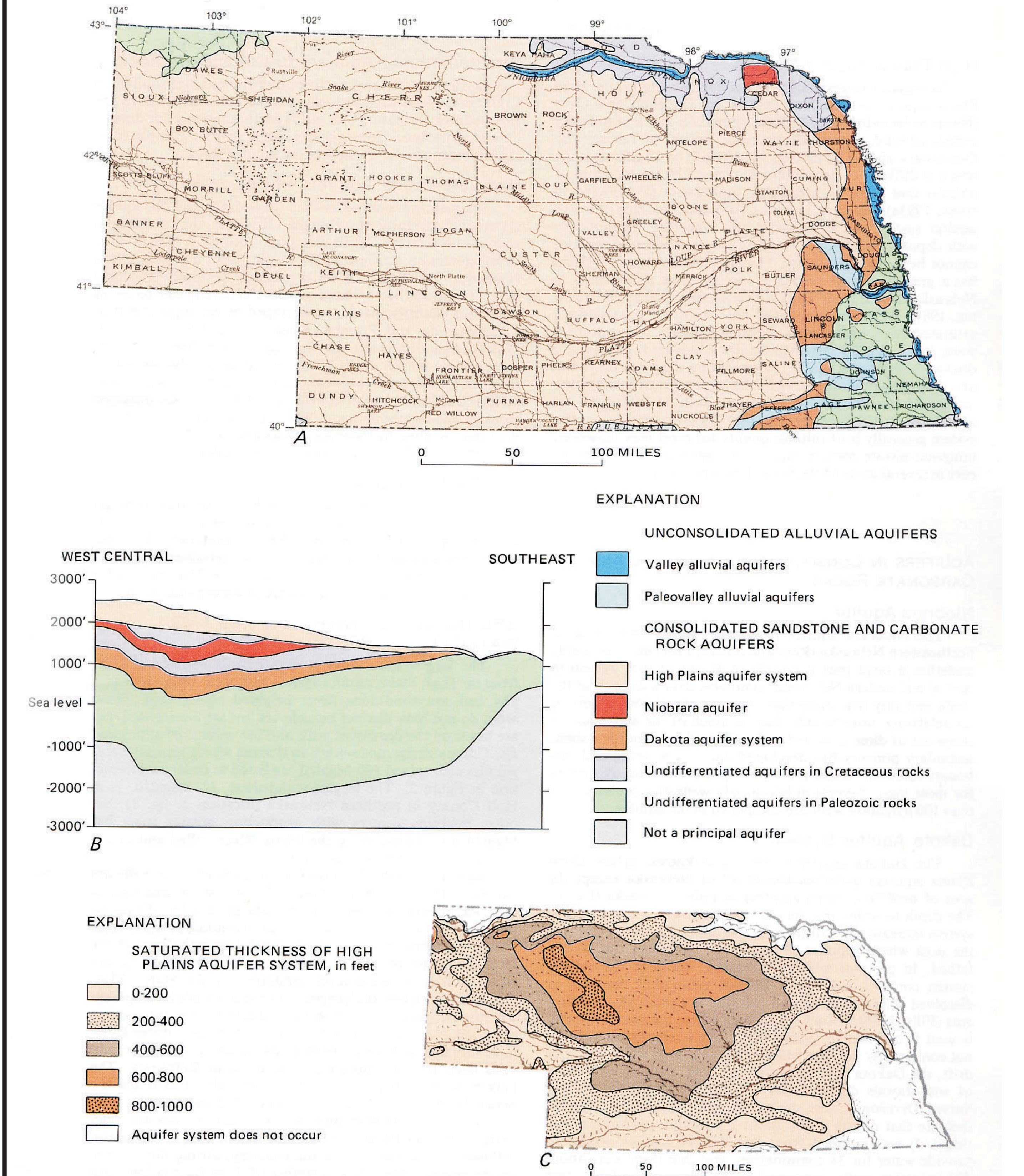
5/29/02 kk 1027-WI-12.cdr	Figure A8-12



Counties, Aquifers, and Physiographic Provinces of Iowa

(National Water Summary, 1984)

5/29/02 kk 1027-WI-11.cdr	Figure A8-11



Counties, Aquifers, and Physiographic Provinces of Nebraska

(National Water Summary, 1984)

5/29/02 kk 1027-WI-13.cdr	Figure A8-13